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INTRODUCTION

The *Callithrix* jacchus group is found in tropical rain forests and gallery forest in eastern Brazil. The authoritative studies of the taxonomy of the *C. jacchus* group are those of Hershkovitz (e.g., 1977) and Coimbra-Filho (e.g., 1973,1990). There is large discrepancies about species arrangements of the *C. jacchus* group between them.

The cranium is the center of attention for vertebrate evolutionary morphology because it represents a complex of interactive functional parts including cerebral, respiratory, sensory, postural and masticatory specialization. In holding such a wealth of information it is not unnatural to assume that the cranium may with probability reflect many aspects of evolutionary history (Albrecht, 1978). In the *Callithrix* jacchus group, however, there were few information of its cranial morphology except for *C. jacchus* itself (Wettstein, 1962), since these animals are endangered (Mittermeier et. al., 1987).

Recently, Natori (1994) applied multivariate analysis to cranial measurements to examine interspeicfic relationships of the *C. jacchus* group. For this study, he used only mean of variables in each species. However, within-species variation is a quite important factor to analyze specific difference on the basis of morphometrical data (Arbrecht, 1993). Thus, in the present study, We examine the intraspecific cranial variability of the *C. jacchus* group to verify the taxonomical hypotheses by Hershkovitz and Coimbra-Filho on the morphological relationships.

MATERIALS AND METHODS

For the nomenclature of marmosets, the proposals of Mittermeier *et al.* (1988) were adopted, and the following forms were used in the present study: *C. jacchus*, *C. penicillata*, *C. kuhli*, *C. geoffroyi*, *C. aurita* and *C. flaviceps*. All data were derived from skeletal materials available at the Museu Nacional de Rio de Janeiro (Rio de Janeiro, Brazil) and the U.S. National Museum of Natural History (Washington D.C.).

The following 20 linear measurements of the cranium were taken for this study (Fig. 1): (1) prosthion to lambda, (2) nasion to lambda, (3) nasion to prosthion, (4) nasion to bregma, (5) bregma to lambda, (6) zygion to zygion, (7) euryon to euryon, (8) frontomalare orbitale to frontomalare

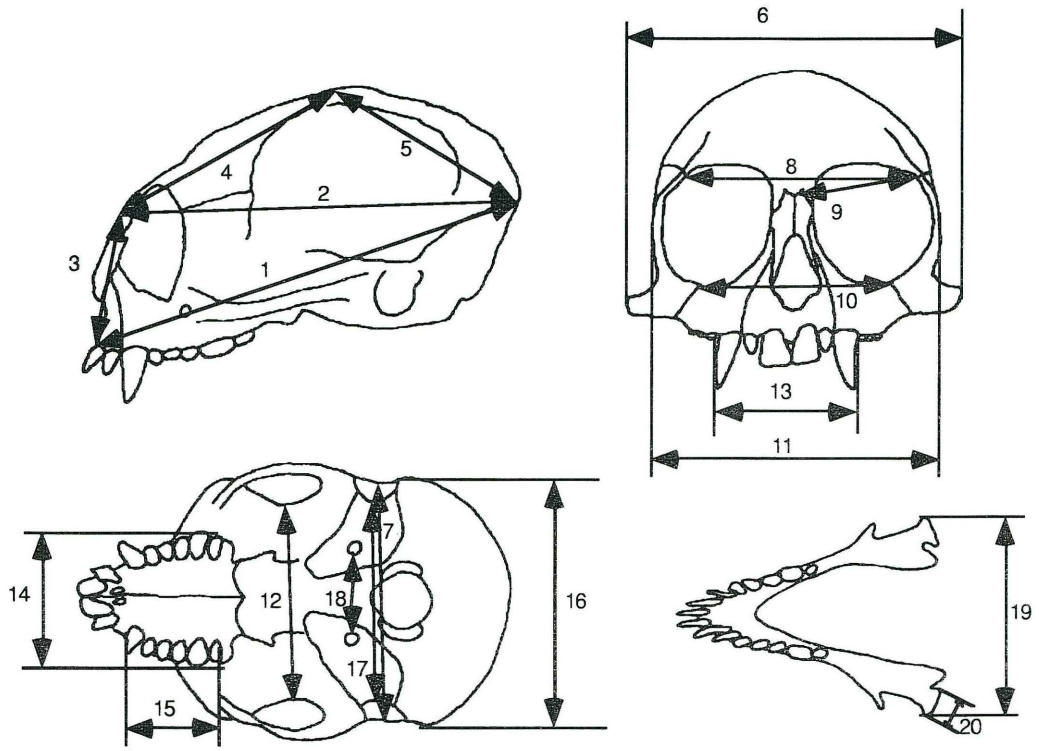

Figure 1. Cranial measurements. Numbers correspond with the measurements described under Materials and Methods.

orbitale, (9) nasion to left frontomalare orbitale, (10) zygomaxillare superior to zygomaxillare superior, (11) greatest breadth across outer margins of orbits, (12) minimum breadth of postorbital constriction, (13) greatest breadth between buccal surfaces of upper canine, (14) greatest breadth between buccal surfaces of first upper molars, (15) mesial surface of left upper canine to distal surface of left second upper molar, (16) auriculare to auriculare, (17) breadth between external openings of external acoustic meatuses, (18) breadth between external openings of carotid canals, (19) bicondylar breadth, and (20) mandibular condyle length.

Discriminant analysis is available for distinguishing not only primate species (e.g., Albrecht, 1978) but biological species in general (e.g., Fisher 1936). Moreover, principal component analysis/factor analysis is designated to discriminate groups on the basis of morphometrical data (e.g., Blachith, R. E. & R. A. Reyment). Thus, we used factor analysis and discriminant function analysis for analyzing taxonomical relationships of the *C. jacchus* group.

RESULTS

Factor analysis was carried out on the basis of correlation matrix using the pooled-marmoset samples with no missing value. The first three factors show eigenvalue greater than 1.0 and their cumulative proportion of the total variance is 0.773. Varimax rotation method was applied to the original matrix of the factor loading for making the interpretation of each factor easier. In the present case, We took loading of the value of 0.6 or over. After the rotation (Table 1), the first factor shows

Table 1. The rotated factor loadings and eigenvalues of the first three factors.

Variable	1	2	3
1	0.3865	0.3776	-0.6994
2	0.3727	0.3758	-0.6678
3	0.4558	0.1105	-0.5688
4	0.3911	0.3396	-0.1575
5	0.1454	0.1198	-0.7097
6	0.5338	0.554	-0.4364
7	0.3687	0.4395	-0.6393
8	0.9399	0.0928	-0.1975
9	0.682	0.0753	-0.2192
10	0.4184	0.1326	-0.41
11	0.7433	0.2205	-0.2192
12	0.5543	0.1229	-0.6745
13	0.1229	0.5151	-0.1911
14	0.1792	0.1663	-0.8043
15	0.28	0.1417	-0.6178
16	0.4211	0.3938	-0.6023
17	0.146	0.7015	-0.0433
18	0.01	0.7571	-0.171
19	0.1169	0.6375	-0.4699
20	0.1401	0.247	-0.507
Eigenvalues	9.610	1.601	1.232

the orbital width because frontomalare orbitale to frontomalare orbitale, maximum length of orbit and zygomaticomaxillare superior to zygomaticomaxillare superior have the large value. The second factor shows large values in the breadth between external openings of external acoustic meatuses and bicondylar breadth (Table 1). Accordingly, the second axis is a factor of width in the auditory region. The third factor represents the braincase size since the measurement items of the braincase have high values in the factor loadings (Table 1).

In plots of individuals on the first and second axes (Fig. 2a), it is difficult to distinguish each form. In projection on the first and third factors (Fig. 2b), *C. jacchus* and *C. penicillata* are completely distinguishable from the other forms. *C. geoffroyi* are able to distinguish from the other forms.

Multiple discriminant analysis was applied to craniometrical data of *C. jacchus*, *C. penicillata*, *C. kuhli*, C. goeffroyi and *C. aurita*. In the present case, *C. flaviceps* was excluded for this analysis, because We obtained only one specimen in this species. For the discriminant function, the following varieties are significant ($P<0.05$) to distinguish the five forms; zygion to zygion, nasion to left frontomalare orbitale, greatest breadth between buccal surfaces of upper canine, greatest breadth

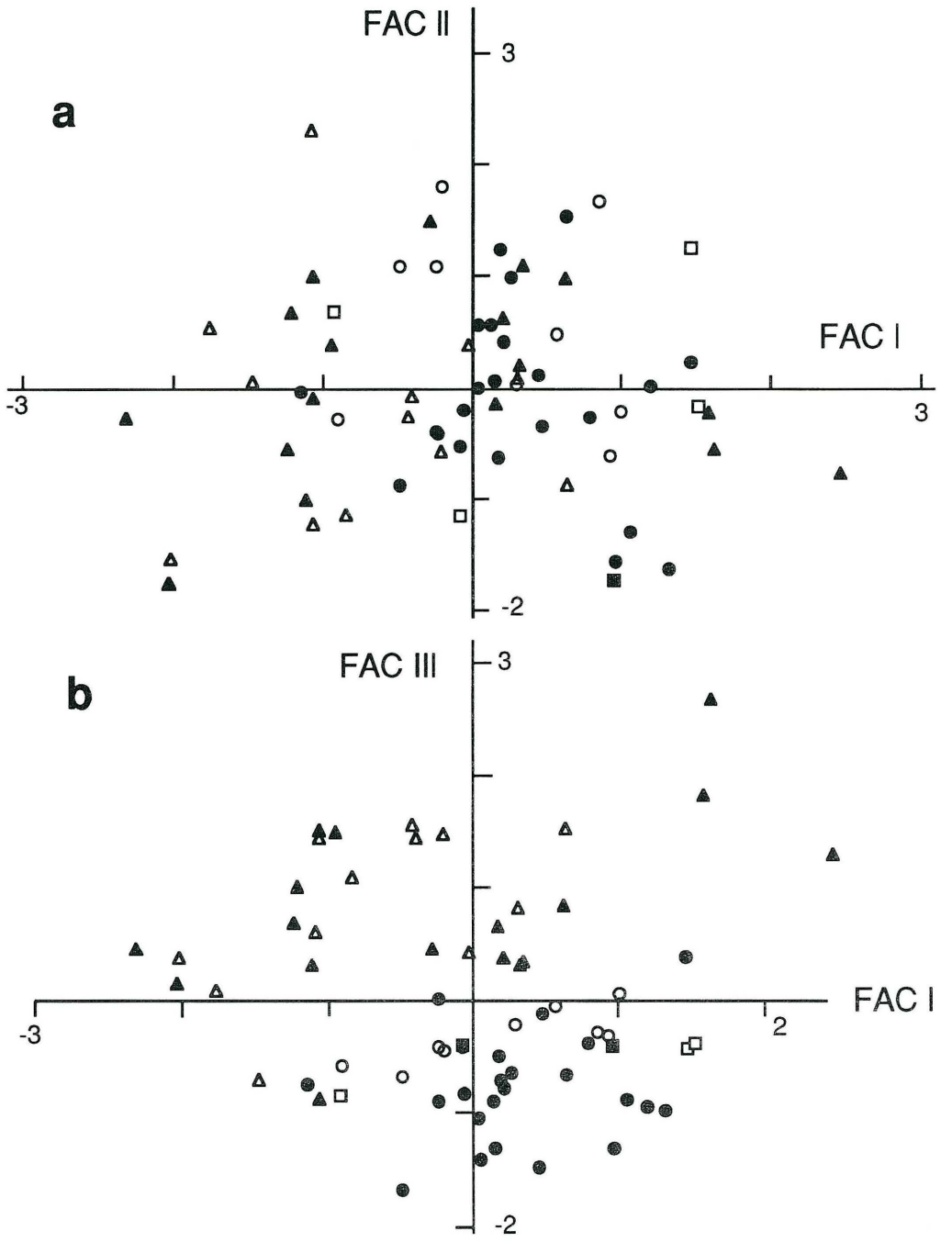

Figure 2. Factor analysis of the C. jacchus group: (a) plots of individuals on the frist and second factors; (b) plots of individuals on the frist and third factors. Open triangle shows C. jacchus; sorid triangle, C. penicillata; open circle, C. kuhli; sorid circle, C. geoffroyi; open square, C. aurita; and solid square, C. flaviceps.

Table 2. Number of cases classified on the basis of multiple discriminant function analysis.

	C. jacchus	*C. penicillata*	*C. kuhli*	*C. geoffroyi*	*C. aurita*
C. jacchus	10	2	0	0	0
C. penicillata	1	16	0	0	0
C. kuhli	0	0	9	0	0
C. geoffroyi	0	0	1	22	0
C. aurita	0	0	0	0	0

between buccal surfaces of first upper molars, mesial surface of left upper canine to distal surface of left second upper molar, breadth between external openings of external acoustic meatuses, and breadth between external openings of carotid canals. This analysis demonstrated significant differences among the five forms ($P<0.0001$). Misclassification slightly occurred between *C. jacchus* and *C. penicillata*, and between *C. kuhli* and *C. geoffroyi* (Table 2). Based on the discriminant function, *C. flaviceps* is grouped into *C. geoffroyi*.

Canonical variate analysis of *C. jacchus*, *C. penicillata*, *C. kuhli*, *C. geoffroyi* and *C. aurita* was performed on the basis of the craniometrical data (Table 3). In scatter plots of individuals on the first and second axes (Fig. 3a), it is possible to discriminate among the following three groups; (1) *C. jacchus* and *C. penicillata*, (2) *C. geoffroyi* and *C. kuhli*, and (3) *C. aurita*. In plots on the first and third axes (Fig. 3b), *C. jacchus* and *C. penicillata* cannot be discriminated from each other, but the others are recognized as a distinct morphological form.

DISCUSSION

C. jacchus, *C. penicillata*, *C. geoffroyi*, *C. flaviceps* and *C. aurita* were once recognized as different subspecies within the *C. jacchus* group (e.g., Napier & Napier 1967). Hershkovitz (1977) lumped these five forms as subspecies of a single species of *C. jacchus*. On the other hand, Coimbra-Filho and his colleagues considered the five forms as valid species (Coimbra-Filho & Mittermeier, 1973; Mittermeier & Coimbra-Filho, 1981; Mittermeier *et al.*, 1988, Rylands *et al.*, 1993). Moreover, they classified *C. kuhli* into a distinct species (Mittermeier *et al.*, 1988; Rylands *et al.*, 1993) although Hershkovitz (1977) recognized this marmoset as a hybrid population between *C. penicillata* and *C. geoffroyi*. Recently, Coimbra-Filho (1990) re-taxonomized Brazilian primates, who treated *C. flaviceps* as a subspecies of *C. aurita*. Rylands (personal communication) suggested the possibility that *C. jacchus* and *C. penicillata* were not distinct species from each other.

In the present study, We obtained the following results. [*C. jacchus* and *C. penicillata*], *C. kuhli*, *C. geoffroyi* and *C. aurita* are distinct morphological forms from one another. It is difficult to discriminate *C. jacchus* from *C. penicillata* based on the present morphometrical study. Taxonomical status of *C. flaviceps* is uncertain because We got only one specimen. However, this marmoset, if anything, is similar to *C. geoffroyi*. These results suggest the following species arrangements of the marmosets: (1) *C. kuhli*, *C. geoffroyi* and *C. aurita* are distinct species; (2) the three species are different from *C. jacchus* and *C. penicillata*, which exhibit subspecific difference; (3) *C. flaviceps* is

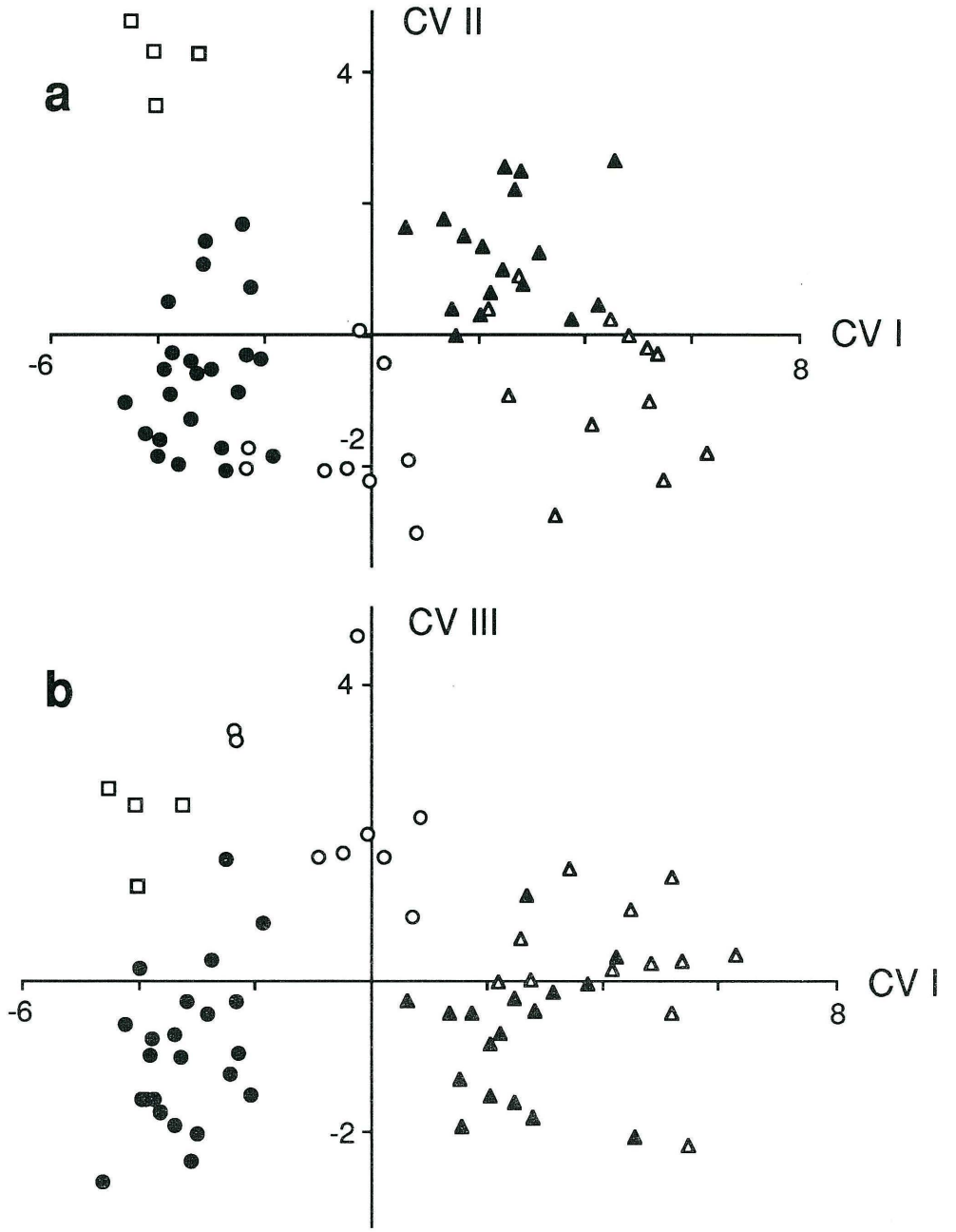

Figure 3. Canonical variates analysis of the *C. jacchus*: (a) plots of individuals on the first and second axes; (b) plots of individuals on the first and third axes. The symbols are explained in Fig. 2.

Table 3. Eigenvalues and eigenvectors of the first three canonical axes.

Variable	1	2	3
1	-0.0686	-0.2318	-0.7919
2	0.0412	0.5634	1.9223
3	-0.1323	-0.3705	0.073
4	-0.0065	-0.4854	-1.1053
5	-0.1347	-0.4668	-0.6326
6	-0.6331	-0.0759	-1.1606
7	-0.0076	-0.5983	-0.5136
8	1.2507	0.4803	0.8905
9	-2.6384	-0.0785	0.6838
10	-0.2691	-0.6582	-0.1061
11	-0.7987	0.3521	-0.2559
12	-0.2429	0.6522	-0.156
13	2.6522	-1.8676	1.9381
14	-1.6981	0.7929	0.2967
15	-1.2425	-2.1886	-0.3963
16	0.6337	0.5811	0.7831
17	1.297	0.1903	-0.4818
18	-0.6582	0.3975	1.1631
19	-0.6932	0.7298	0.2779
20	0.0693	-0.4123	-0.1823
Eigenvectors	10.6348	2.3006	1.7641

not one subspecies of *C. aurita*. This corresponds with the species arrangements of the eastern Brazilian marmosets by Rylands (personal communication).

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